Fifth-year Results of a Slash Pine Polycross Progeny Test in Georgia

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In 1954, seed orchards of selected slash pine **(Pinus elliottii Engelm.)** and loblolly pine **(P. taeda L.)** were established in Georgia by the Georgia Forestry Commission to develop and produce superior seed. Progeny testing of the selected trees was initiated as soon as pollen production and female flowering were sufficiently abundant in the orchards to permit controlled pollinations.

This paper reviews the fifth-year results of the first slash pine progeny test to be outplanted. This planting tests 35 of 179 slash pine clones in phase' I of the progeny testing program used by the Georgia Forestry Commission to develop its seed orchards.

Phase I involves controlled pollinations of all slash and loblolly pine clones in the orchards with a mixture of pollen from 15 or more clones in the orchards. Two other phases complete the program. Phase it consists of pollinating 30 clones each of slash and loblolly pine with the pollen of at least five different clones of the relevant species. In phase III those clones used in phase II will be self-poll inated.

The objectives of phase I and of this progeny test are: (1) to estimate, on the basis of several important traits, the general combining ability of each clone; i. e., what the relative performance, or breeding value, of each open-pollinated clone might be when the orchards are at full seed production; (2) to provide a basis for roguing undesirable or relatively inferior clones so that seed certification requirements defined by the Georgia Crop Improvement Association may be met (1965, G.C.I.A. Certification Standards for forest tree seed, pp. 80-84); and,(3)to identify those clones that are exceptional in the most important traits and which are, therefore, preferable for use in further crosses.

These objectives and other considerations have been reviewed in greater detail by Barber (1958) [3]/ and by Webb and Kraus (1966).

MATERIALS AND METHODS

This test is composed of two contiguous outplantings, plantations 57 and 58. Each plantation contains progenies of 19 clones and one commercial check lot. Three progenies are included in both plantations for purposes of comparison, so that 35 half-sib families are studied.

All clones involved in this test were pollinated in 1958 with a mixture of the pollen of 30 clones from the orchards. This mixture was designated mix I and represented all the clones from which sufficient pollen was available at that time. This procedure was chosen so as to give a good approximation of the pollinations between clones as they might naturally occur in the seed orchards, assuming seed orchard pollen was abundant and contamination from outside sources was insignificant (Barber, 1958). [3]/

The seed lots used as the controls in this study were collected from Georgia Forestry Commission forestry districts within the natural range of slash pine in south Georgia. They were intended to represent the general genetic quality of seed being used to establish plantations in Georgia when this study was initiated.

The outplanting is located in Bleckley County, Georgia, on the upper coastal plain. Both plantations were established in January 1961 with 1-0 nursery stock. Each plantation is arranged in a randomized complete-block design with six replications. The trees are planted at an 8.5 x 8.5 foot spacing in 25-tree square plots. Because of an insufficient supply of seedlings of certain progenies in the nursery at the time of planting, there are two missing plots in plantation 57. Plantation 58 is complete.

Measurements

Two of the measurements were executed during

1/Cooperators in this study were: the Georgia Forestry Commission, the Continental Can Company, and the Georgia Forest Research Council.

2/Assistant Silviculturist, and Plant Geneticist, respectively; Southeastern Forest Experiment Station, Forest Service, Macon, Georgia.

3/ Barber, John C. Preliminary work plan for the progeny testing of trees used by Georgia Forestry Commission in the development of seed orchards. Southeastern Forest Experiment Station, Macon, Georgia. 1958. (Unpublished; 18pp.).

the month of November 1965, as follows: (1) total height was determined with a pole graduated to the nearest tenth foot, and (2) the number of stem and branch cankers caused by fusiform rust (**Cronartium fusiforme** Hedgc. and Hunt ex Cumm.) were counted on each tree. These measurements had also been recorded in 1963 after three growing seasons in the field. A third measurement, the crown width/total height ratio, was taken in March 1966 shortly before new growth was initiated. This trait was measured with a transparent plastic board cal ibrated so as to give the measurements as direct readings in units of ten percent. Since all data for each tree were recorded on IBM Mark-Sense cards, the number of cords per plot gave an automatic tally of survival.

Statistical Methods

Plot means were calculated for all variables, which consisted of: (1) number of trees surviving; (2) total height; (3) crown width/total height ratio; (4) average number of cankers per tree; (5) average number of cankers per infected tree; (6) percentage of trees free of rust; and (7) percentage of trees with stem cankers.

The percentages of trees free of rust and trees with stem cankers were transformed to arcsin /percent. All seven variables were then subjected to analysis of variance, which consisted of the standard F-test of the randomized complete-block design. Simple and partial phenotypic correlation coefficients between some of the variables measuring rust infection were calculated in an attempt to determine which parameter best represented the patterns of rust infection.

Duncan's new multiple range test was used to compare the progenies for total height, the crown width/total height ratio, and the average number of cankers per tree. Finally, regression analysis was used to rank all progenies in both plantations together on the basis of the three common progenies. In this manner, all progenies in both plantations were compared directly with each other and evaluated according to the above three traits.

DISCUSSION OF RESULTS

Fifth-year survival was 93 and 91 percent for plantations 57 and 58, respectively, and the range in each plantation varied from 87 to 97 percent. Because very little variation between progeny lines was indicated for survival (table 1), it was not included in any further analysis.

Analysis of Variance

There were significant differences between progenies for all variables except total height in plantation 57, percentage of rust-free trees in plantation 58, and survival in both plantations (table 1). The percentage of trees with stem cankers was significant at the 5 percent level in plantation 58, but all other differences were highly significant.

Reliability of Earlier Measurements

Date on total height and rate of infection (percentage of rust-free trees) had also been recorded after three years in the field. In order to test the

Table 1. — Summary of F-tests of slash pine progenies in Plantations 57 and 58

Source of variation	Degrees of freedom	Number of trees per plot	Total height	Crown width/ total height ratio	Average No. of cankers per tree	Average No. of cankers per infected tree	Percentage of rust-free trees	Percentage of trees with stem cankers
				Plantation 57				
Block	5	2.72*1/	7.51**	16.55**	5.69**	4.14**	3.19*	3.34**
Progeny	19	1.01 NS	1.42 NS	4.50**	7.66**	3.58**	13.56**	4.47**
Error	932/							
				Plantation 58				
Block	5	0.80 NS	10.37**	0.99 NS	5.56**	4.17**	2.70*	2.61*
Progeny	19	.92 NS	2.28**	9.11**	4.53**	4.47**	1.68 NS	2.05*
Error	95							

1/ * Significant at the 5% level
** Significant at the I% level.
NS Not significant

2/ Two degrees of freedom lost due to missing plots.

reliability of the earlier measurements, correlations between the third- and fifth-year data of five variables were calculated (table 2). Although most of the correlations for rust-infection parameters were high in plantation 57, they were low in plantation 58. Such erratic results imply that after three years the overall severity of rust infection may not have been sufficient to give an accurate evaluation of the rust resistance of the progeny lines. It is generally considered that favorable conditions for severe rust infection must be present for an adequate test of resistance to the disease. At five years of age, the probability that all progenies have been thoroughly exposed to infection is much greater. It also may be assumed that after five years most of the infection that may reduce the merchantability of the trees has occurred. Thus, third-year measurements do not seem to be very reliable for determining the relative rust resistance of progeny lines. However, such an estimate of the accuracy of the fifth-year rust infection data must await the tenth-year measurements.

Table 2. — Summary of simple phenotypic correlations between third and fifth year measurements of slash pine progenies in Plantations 57 and 58

Variables compared	Correlation coefficient (r) 1/	
Third year measurements vs. Fifth year measurements	Plantation 57	Plantation 58
Total height	0.871**	0.923**
Average number of cankers/tree	0.594**	0.265 NS
Average number of cankers/infected tree	0.296 NS	—0.301 NS
Percentage of trees free of rust	0.626**	0.390 NS
Percentage of trees with stem cankers	0.611**	0.506*

Selection of Variables

Of the seven variables analyzed, four deal with the degree of rust infection. In an attempt to determine which variable might have the greatest general utility for analyzing inherent disease resistance, several simple phenotypic correlations between three of these parameters were calculated (table 3).

It would seem that these generally high correlation coefficients are to be expected simply because all three variables are expressions of rust

Table 3. — Simple phenotypic correlations between selected variables of slash pine progenies in Plantations 57 and 58

Variables compared	Correlation coefficient (r)	
	Plantation 57	Plantation 58
Average number of cankers per tree vs. average number of cankers per infected tree	0.868**	0.976**
Average number of cankers per tree vs. percentage of trees free of rust	—0.851**	—0.802**
Average number of cankers per infected tree vs. percentage of trees free of rust	—0.486*	—0.686**

[17] Values which exceed ±0.444 are significant at the 5% level (*). Values which exceed ± 0.561 are significant at the percent level (**).

infection. However, the percentage of trees free of rust and the number of cankers per infected tree are parameters which represent separate subpopulations; i. e., they are unrelated and have different means and variances. Because of this difference in population characteristics, the significant correlation between these two variables is meaningful. That is since this correlation was significant in both plantations and was not confounded with any other effects, it can be interpreted to mean that those progenies with fewer infected trees are more likely to have fewer cankers on the infected trees. Those results are in agreement with findings reported by Goddard and Strickland (1966, p. 11), who found a significant negative correlation (r = —0.57*) between the percentage of trees free of rust and the severity of rust on infected slash pine trees (number of cankers per infected tree).

On the other hand, any variation in either the number of uninfected trees or the number of cankers per infected tree will affect the average number of cankers per tree. Also, the relationship of the average number of cankers per tree to each of the other variables is confounded by the fact that they are significantly correlated with each other. For example, it could not be concluded that the relationship between the average number of cankers per tree and the percentage of trees free of rust would be the same if a different set of values for the number of cankers per infected tree were considered.

To clarify these relationships, partial correlation coefficients were calculated such that the average number of cankers per tree was correlated with each variable while the alternate variable was held constant (table 4). These very high partial correlations indicate that in this study the average number of cankers per tree reflected quite accurately both the rate of infection and the severity of attack on each progeny. Also, as shown in table 1, highly significant differences between progenies were obtained for this variable in both plantations. On the basis of these statistics, it seems reasonable to conclude that the average number of cankers per tree is the most useful single variable for evaluating the resistance to rust infection among progeny lines. Therefore, the remaining portion of this discussion is limited to the following three variables: (1) total height; (2) the crown width/total height ratio; and (3) the average number of cankers per tree.

Multiple Range Tests

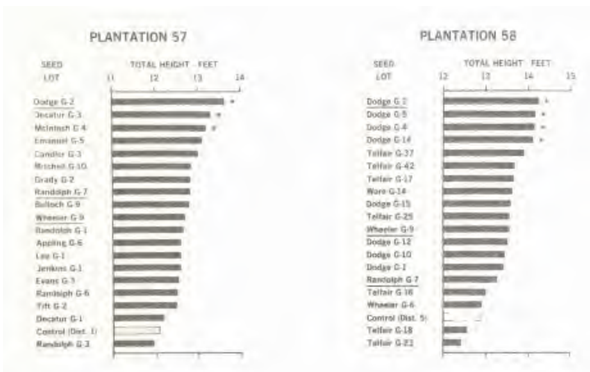
Generally, progeny performance relative to the controls was very good. In the Duncan's new multiple range test for total height, the control lots ranked poorly in both plantations (figure 1). In plantation 57 three progenies were significantly better at the five percent level than the control, which ranked next to last; in plantation 58 four progenies were significantly higher than the control which ranked eighteenth.

This trend was even more striking for the crown width/total height ratio (figure 2). In both plantations the controls ranked next to last. In plantation 57, six progenies had significantly narrower crowns than the control, and in plantation 58, seventeen were significantly better.

Table 4. — Partial correlations between selected variables of slash pine progenies in Plantations 57 and 58

Variables compared	Correlation coefficient (r, 1/)	
	Plantation 57	Plantation 58
Average number of cankers per tree vs. average number of cankers per infected tree (percentage of trees free of rust held constant)	0.989**	0.993**
Average number of cankers per tree vs. percentage of trees free of rust (average number of cankers per infected tree held constant)	—0.986**	—0.949'

1/ Values which exceed +- 0.575 are significant at the 1 percent level (**).



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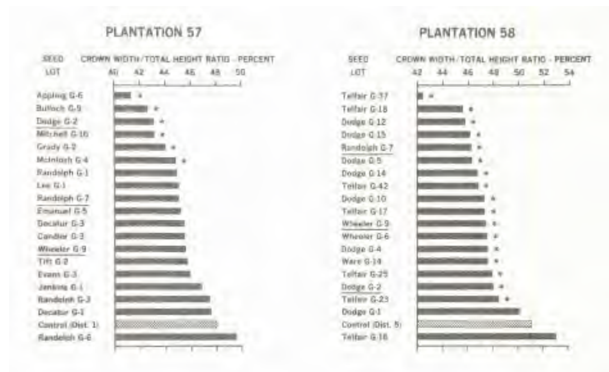

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Improvement was much less convincing for rust resistance (figure 3). In plantation 57, seven progenies had significantly fewer cankers than the control, but five progenies ranked lower than the control. In plantation 58, only one progeny significantly outperformed the control, which outranked 12 progenies. A more intensive method of selection for rust resistance seems to be needed.

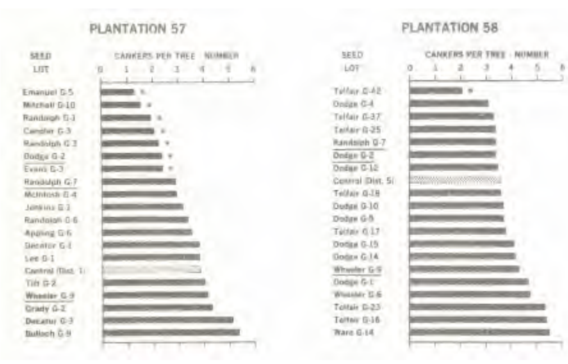

Figure 3. Progeny lines and controls in Plantations 57 and 58 ranked according to the average number of cankers per tree. Underscored progenies are common to both plantations (+ indicates progenies with significantly fewer cankers per tree at the 5 percent level than the control).

Evaluation of Progeny Lines

Three progenies are common to both plantations. The relative performances of these progenies in each plantation were used to adjust all progeny lines to a common base so that they could be compared directly with each other. To accomplish this, regressions of the three progeny means for each variable in plantation 58 on their corresponding means in plantation 57 were calculated. The prediction equation for each variable was then used to adjust all progenies in plantation 57 to the same base as those in plantation 58. The correlation coefficient (r) between plantations for each variable was also calculated. None of these correlations were significant, but two of them were high. They were: (1) for total height, r 0.912; (2) for the average number of cankers per tree, r = 0.942; and (3) for the crown width/total height ratio, r = 0.316 (based on only two common progenies, since Dodge G-2 was so far out of line that it reversed the slope of the regression equation). The required $r_{.05}$ was 0.950. Nevertheless, the use of regression seems justifiable as a practical method of comparing the performances of all lines from both plantations.

To evaluate the progeny lines for all three traits, total height is plotted over the crown width/total height ratio (figure 4) and over the average

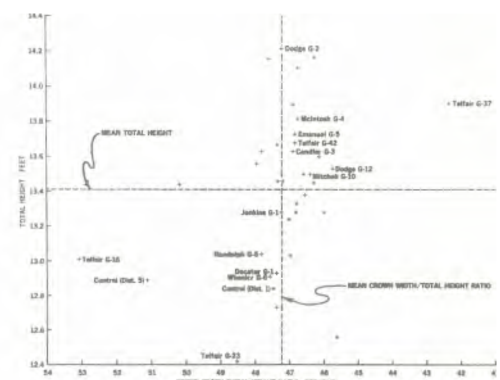

Figure 4. Slash pine progenies ranked according to the relationship of total height vs. the crown width/total height ratio.

number of cankers per tree (figure 5). The mean of all progenies for each trait is indicated by horizontal and vertical lines on each graph. In figure 5 a second vertical line denotes a control (District 5). Since the value for this control is superior to the mean number of cankers per tree, it is used instead of the mean to evaluate the progenies for that trait. Thus, all clones whose progenies excelled either

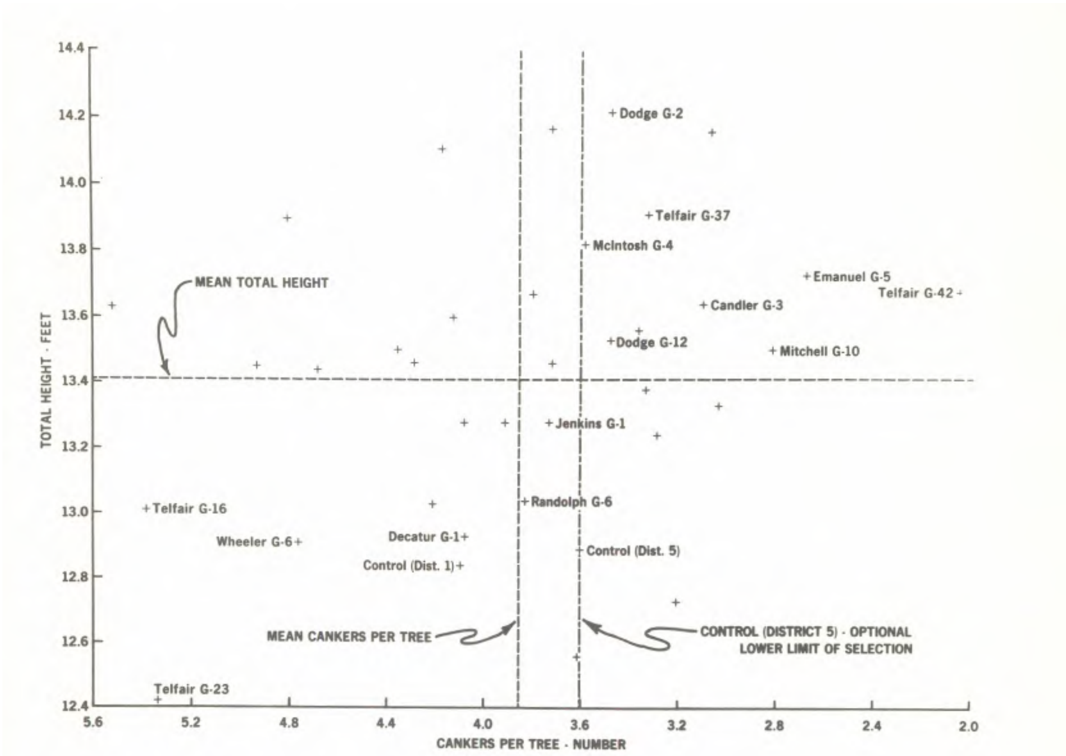

Figure 5. Slash pine progenies ranked according to the relationship of total height vs. the average number of cankers per tree.

the mean or the best control (if the control was better than the mean) for all three traits are considered superior and are therefore recommended for future breeding work. Graphically this means that those progenies which fall in the upper right quadrant of each graph are considered superior and are labelled. Conversely, the clonal parents of those progenies which fall below all three means (the lower left quadrant of each graph)may be considered undesirable and could be culled from the seed orchards if necessary. These are also labelled, but all other progenies are not. Of the total of 35 clones, eight are superior. These are Dodge G-2, Dodge G-12, Telfair G-37, Telfair G-42, McIntosh G-4, Emmanuel G-5, Candler G-3, and Mitchell G-10. It should be noted that most of these "superior" lines performed well when ranked according to the other expressions of rust infection that were also analyzed. On the other hand, there are six progeny lines which are below average in all three traits. These "inferior" progenies are Telfair G-16, Telfair G-23, Jenkins G-1, Randolph G-6, Decatur G-1, and Wheeler G-6.

Actually clones will be rated on many traits such as wood quality, seed production or anything else that may show up in tests and which is important in seed orchard use. Also, results from Phase II and Phase III of the progeny testing program may provide important information useful in culling clones.

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